Defense Science Board Task Force on

MISSILE DEFENSE PHASE III MODELING AND SIMULATION

MARCH 2004

Office of the Under Secretary of Defense
For Acquisition, Technology, and Logistics
Washington, D.C. 20301-3140

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **MAR 2004**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Defense Science Board Task Force on Missile Defense Phase III Modeling and Simulation**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Office of the Under Secretary of Defense For Acquisition, Technology, and Logistics Washington, DC 20301-3140**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**95**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

OFFICE OF THE SECRETARY OF DEFENSE
3140 DEFENSE PENTAGON
WASHINGTON, DC 20301-3140

DEFENSE SCIENCE BOARD

MEMORANDUM FOR UNDER SECRETARY OF DEFENSE (ACQUISITION, TECHNOLOGY & LOGISTICS)

SUBJECT: Final Report of the Defense Science Board (DSB) Task Force on Missile Defense Phase III – Modeling and Simulation

I am pleased to forward the final report of the DSB Task Force on Missile Defense Phase III—Modeling and Simulation. This report evaluates the state of modeling and simulation (M&S) efforts supporting the Ballistic Missile Defense System and makes recommendations for improving future M&S development.

Modeling and simulation plays a unique and central role in the development of the missile defense program. Effective modeling and simulation is the sole means to assess overall system performance and quality, train and operate at the system level, and look beyond current system plans and programs. The task force addresses these critical features and also recommends methods to improve confidence in the validation and accreditation of the various levels of models and simulations.

I endorse all of the Task Force's recommendations and propose you review their report.

William Schneider, Jr.
DSB Chairman

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DEFENSE SCIENCE
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MEMORANDUM FOR THE CHARIMAN, DEFENSE SCIENCE BOARD

SUBJECT: Report of the Defense Science Board Task Force on Ballistic Missile Defense Phase III: Modeling and Simulation

Modeling and simulation (M&S) plays a key role in both developing the Ballistic Missile Defense System and assessing its likely effectiveness. M&S for missile defense is an expansive undertaking, ranging from detailed engineering simulations of individual components to system-of-system level simulations. The Defense Science Board Task Force was asked to assess five specific areas involving modeling and simulation for the missile defense program:

- The scope of the modeling and simulation effort
- The appropriateness of the level of fidelity
- The impact of communication on the end-to-end models
- The approaches to the validity of simulations
- Additional opportunities for M&S contributions

Flight tests for missile defense systems in today's environment require substantial time, resources, and expertise. Much more than in earlier missile defense programs, today modeling and simulation must be relied upon to account for all pieces of the program, the resources that go into all those pieces, and the integration of the program elements into a single system-of-systems. Thus, modeling and simulation is a critical part of the overall missile defense program.

To assure that modeling and simulation fulfills its role, the Task Force makes the following bottom line findings and recommendations, which are addressed in detail in the body of the report.

- Missile defense models and simulations are needed to provide analytical underpinnings for system design, development, and operations. To perform this role, the many individual models and

simulations need to be more adequately linked and integrated, at the system level, with appropriate levels of fidelity.

- Missile defense development, deployment, and testing must be supported by adequate system level models. The Missile Defense Agency (MDA) should specify the system-level model that will be used for system effectiveness assessment and require that all elements in the program provide appropriate models to interface with the system-level model. The linkages that currently exist between models do not provide the needed insight to support system-level development, deployment, and testing.

- A significant modeling and simulation program needs to be oriented to support future development of the Ballistic Missile Defense System at the block level. M&S representations should be developed and delivered for each block upgrade.

- Improvements are needed in the verification, validation and accreditation processes for missile defense models and simulations. Ownership of the verification and validation and, separately, of the accreditation processes at a senior level should be established. A primary responsibility for this individual is to obtain outside expertise to provide MDA with increased confidence in block model representations, given the complexity of the missile defense system.

- To provide adequate management attention to the critical role of modeling and simulation, MDA should establish a Modeling and Simulation Executive within its organization, reporting to the Director. This individual should be responsible for funding, acceptance, delivery, and maintenance of the M&S software for each component, element, and block.

By implementing the recommendations contained in this report, and summarized here, the MDA can strengthen its current modeling and simulation effort to meet the needs of such a complex and important program.

General Larry Welch, USAF (ret.)

Dr. William Graham

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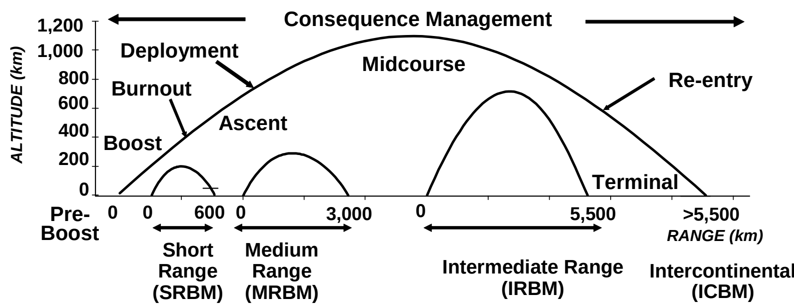
EXECUTIVE SUMMARY

Terms of Reference

- Phase I – Reported in May 2002 - Assess the program for mid-course discrimination
- Phase II – Reported in October 2002 - examine:
  - Capability need (evolution of ballistic missile threats)
  - International cooperation
  - Boost phase technology
  - Battle management, command and control, and communications
- Phase III – Modeling and Simulation – assess:
  - The scope of the modeling and simulation effort
  - The appropriateness of the level of fidelity
  - The impact of communication on the end-to-end models
  - The approaches to the validity of simulations
  - Additional opportunities for M&S contribution

This report covers Phase III of the work of the Defense Science Board (DSB) Task Force on Missile Defense. Phase I examined mid-course discrimination. Phase II, a 2002 DSB Summer Study, examined the four issues shown in the chart above. Following completion of the Phase II report, the Director, Missile Defense Agency (MDA) asked the Task Force to examine modeling and simulation (M&S). The Under Secretary Defense for Acquisition, Technology and Logistics (USD[AT&L]) concurred. The request was further refined to the five areas shown. After a brief introduction, this report will cover each of the five issues in turn.

An Integrated Layered Defense Against Missiles of All Ranges



Capability-based requirement: ***Defeat missiles of all ranges in all phases of flight***
Development approach: ***Spiral development to field incremental improvements towards the capability goal***

This chart is a reminder of the scope of the effort that modeling and simulation must serve. The end capability required is a capability to defeat missiles of all ranges in all phases of flight. This capability is to be achieved with spiral development—fielding increments of capability that build toward the end objective.

Bottom Lines

- Credible modeling and simulation (M&S) is essential to development, testing and deployment. It provides the only way/place that can:
  - Account for the how & why of full program spending
  - Integrate all the parts
  - Solve element problems at the architecture level
  - Test at the architecture/integrated system level
  - Assess Ballistic Missile Defense (BMD) integrated system quality and reliability
  - Explore the full operating envelope
  - Look beyond current plans and programs
  - Demonstrate to the user/operator how the system is expected to perform in potential scenarios
  - Train and operate at the system level

This chart and the five that follow offer the bottom line findings and recommendations of the Task Force. Subsequent sections will provide the detail underwriting these bottom lines. This first chart provides a broad picture of the demands on modeling and simulation to support MDA development, acquisition, and operation. Given the nature of the missile defense program, M&S plays an unusually central role. As indicated, it is the only way to account for all the pieces of the program, the resources that go into all those pieces, and their integration into elements (e.g., ground-based missile defense, kinetic boost phase, Aegis, and PAC-3) and into the system of systems. It is the only way to assess overall performance and quality. M&S is also the only way to train and operate at the system level. The remaining bottom lines charts are self-explanatory.

Bottom Lines (cont.)

- To provide needed analytical underpinnings for system design, development, and operations, MDA models and simulations need to be more adequately linked and integrated with appropriate fidelity
  - The specific purposes for the various levels of modeling and simulation (from component to campaign) need to be explicitly and authoritatively defined
  - The key MDA models and simulations are legacy models, developed largely as stand-alone models and hence are not well designed to fit together into the needed modeling and simulation system architectures
  - Key models in the family of MDA models and simulations need to be vertically integrated – that is validated, accredited component and element models need to logically feed system level models that, in turn, feed campaign and theater models.
  - Element models need to be horizontally and seamlessly linked and validated for their intended purpose to provide usable system level models
  - The fidelity and credibility of the element and component representations in the system level models are not adequate to provide confidence in model outputs

Bottom Lines (cont.)

- MDA development, deployment and testing must be supported by adequate system level models
  - The national teams (Battle Management Command, Control and Communications [NTB] and Systems Engineering & Integration [NTS]) are developing separate system level models with little communication to determine whether a common model would be a more effective solution
  - "Systems'' and command and control, battle management, and communications (C2/BM/C) models need to be developed in close collaboration to exploit multi-sensor data
  - Integrated discrimination, designation emphasis is needed to ensure that the timelines, latency, and message content provide for needed data fusion in the system design and system simulations
  - The MDA should specify the system level model to be used for system effectiveness assessment and require, contractually, that all elements provide interfacing representations. The Task Force found MDWAR promising though not yet adequate to the task.
  - The M&S focus needs to shift from continuing to expand currently largely adequate element models to filling some glaring gaps (e.g., the discrimination function) and on integrated system level M&S
  - The simulation architectures do not allow the models and simulations to interact as needed to provide the desired insights

Bottom Lines (cont.)

- Support of future development
  - There needs to be a significant M&S program specifically oriented to defined and future conceptual development blocks
  - A system level (Missile Defense Warfare Assessment and Research Simulation [MDWAR]?) M&S deliverable should be developed for each block with appropriate configuration control to assure the user/operator that the representation is valid and credible for envisioned scenarios
  - The system level modeling requirements need to also serve the needs of United States Strategic Command (USSTRATCOM) in filling their global integrated missile defense responsibilities

Bottom Lines (cont.)

- Validation and accreditation
  - Given the complexity of the integrated missile defense task and the limitations on validation through flight testing, hardware-in-the-loop (HWIL) simulations become key to confidence in M&S validity
  - A master “Accreditation Tree” is needed with clearly delineated buyoff dates by M&S users, fully linked to the system development and deployment schedule
  - There is a need for an authoritative library of accredited models at levels from phenomenology and physics to integrated system level models. Accreditation documentation should be specific as to the purposes for which accredited

Bottom Lines (cont.)

- A Modeling and Simulation Executive in MDA, reporting to the Director, is needed to provide adequate management attention to the critical role of Modeling and Simulation
  - Responsible for the funding, acceptance, delivery, and maintenance of the M&S software for each component, element, and block
  - Establish MDA ownership of Systems and C2/BM/C M&S development at senior level with responsibility, authority, and budget to provide coherent product for the user/operator
- Establish (separate) MDA ownership of the independent verification, validation, and accreditation (VV&A) process at a senior level with sufficient resources to engage external, rather than just internal, expertise to provide MDA and the user/operator a confident representation of Block system performance (through assuring that each element of the M&S representation is assessed).
  - Establish a VV&A Quality Assessment/Audit Team with a balance of experienced missile defense element algorithm, C2/BM/C, software experts, and operators that reports to the M&S Executive

CHAPTER 1. SCOPE OF THE MODELING AND SIMULATION EFFORT

This chapter discusses the scope of the DSB study. The Task Force considered overall adequacy to be a part of scope and thus includes findings and recommendations on the overall adequacy and suitability of current M&S and development plans.

Scope of Simulation Needs

- Support program decision points, design trades
- Predict & assesses system performance
- Help develop C2/BM/C capabilities specification
- Help define BMDS spiral and technology development needs
- Support detailed engineering development
- Explore concepts and system trade-offs
- Guide and augment flight testing
- Support exercises, wargames, training
- Identify block system capabilities against ballistic missiles of all ranges in all phases of flight for the user/operator
- Support operational decisions in execution

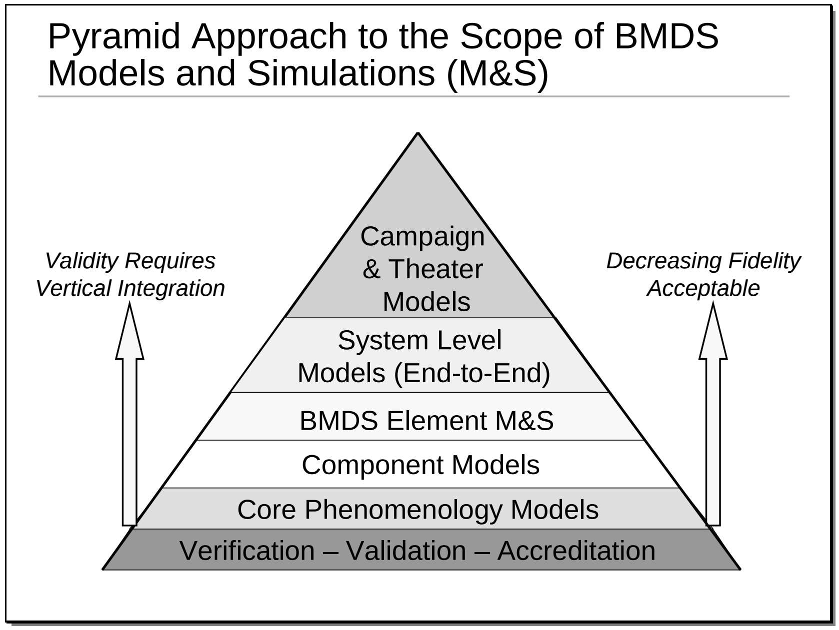
It is critically important to define the purpose of each level of simulation to guide models and simulation development

The scope required for the Ballistic Missile Defense System (BMDS) development blocks is determined by the backgrounds, targets, elements, activities, and systems that M&S must describe adequately to assess overall performance and contributions of the major elements.

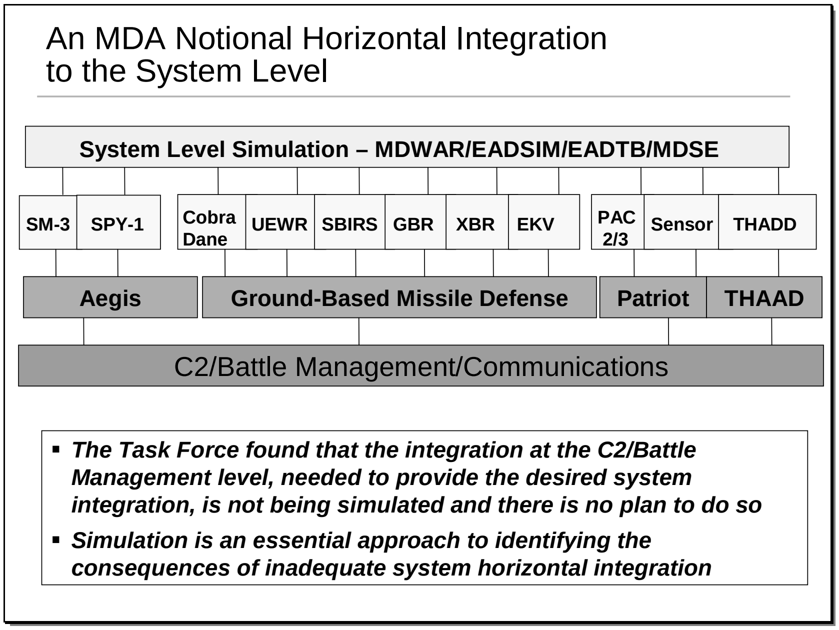
Overall issues include:

- The range of threats and defensive systems that can be analyzed

- Ability to model relevant threats and elements for initial defensive operations (IDO) and subsequent blocks
- Adequacy of the scope to treat IDO and subsequent blocks; complicated in that the systems are still to be defined
- The scope of M&S needed for adequate analyses
- The more specific issues listed in the chart above are taken from the summary MDA briefing at the Joint National Integration Center (JNIC), which defined the specific elements that implicitly define a program of adequate scope



The MDA M&S community makes frequent reference to a pyramid of models of increasing scope and reducing fidelity. In actual practice, the models are not integrated in horizontal layers and there is little linkage to models at higher level of aggregation from those below in the pyramid. These shortcomings and their consequences are discussed further in following charts and sections.



This chart depicts the MDA notional relationship between the system and element models and between models within the vertical layers. However, as noted earlier, the current core models have little or no horizontal integration. Thus, the evaluation of the elements' separate and integrated benefits is uncertain. The system level models do not adequately address the C2/BM/C interface and data flow.

The Heritage and Challenge

- Most current MDA M&S activities are legacy items
  - Developments, in some cases, more than a decade old
  - Many activities originally dominated by needs and interests of the MDAPs
  - Developed under different organizations, in isolation, with different objectives
- The MDA objective to treat M&S as a coordinated effort is only a few years old
  - Focus is primarily at the phenomena and integrated element level with other hierarchical levels mostly being developed autonomously
  - A major part of the strategy and effort and a major challenge is salvaging/converting/migrating/extending legacy items
  - A major issue is the appropriate allocation of resources in achieving the required capability across the M&S classes and elements

There has been a great deal of activity in the Department of Defense (DoD) attempting to integrate M&S into programs and focusing on the issue of fidelity for performance assessment, acquisition support, and training and war games. Most current MDA-specific M&S activities are legacy items, sometimes a decade or more old, and originally developed with different objectives than those now required by MDA. These models are being updated, although plans to use the modernized versions are not clear. Moreover, there appear to be many redundant codes that are maintained for a variety of non-technical reasons. An organized attempt to coordinate MDA M&S activity and resources has only been in place for a few years and has focused primarily on managing the phenomena-, core-, or integration-class simulations.

Element, Activity & Integration Model Shortfalls

- Campaign and theater models - CAPS & JAWARS models
  - Not integrated
  - Not linked to the models below them in the M&S hierarchy
  - Little contribution to increased scope
- System level models
  - MDWAR is a widely used MDA system model
- BMDS model focus is largely on C2/BM/C
- Available element models appear appropriate, but decoupled
  - Models essential for later phases not available (boost phase, discrimination)
- Important candidate future elements are not available (e.g., Space Tracking and Surveillance System [STSS], space-based interceptor, alternative Exoatmospheric Kill Vehicle [EKV])
- Threat, phenomenology models lack essential data (e.g.,hypervelocity impact)
- MDA needs to ensure that core phenomenology models are managed and maintained to ensure availability of valid inputs for the BMDS M&S community

As noted earlier, campaign- Commanders Analysis Planning and Simulation (CAPS) and theater-level Joint Theater Warfighting System (JTWAR) models are currently decoupled from those below them in the M&S pyramid. They do not explicitly guide or draw on the results of MDWAR level simulations. They use independent, shorthand versions of engagements that are fast and convenient to run, but that do not provide confidence in the validity of the insights.

Force-on-force, mission, and system integration level models are redundant, do not treat distinct levels of aggregation, and are not closely coupled to element level models. They contain similar but independent aggregated models of elements and communication, which have not been extensively compared.

MDWAR appears capable of adequate scope and extension to the level of sensors, interceptors, communications, and command control (C2) needed for near-term system level studies. Even so, it currently has significant limitations discussed on the next chart.

Ballistic missile defense activity-level models are immature and decoupled. Only the battle management and communications (BMC) has significant coupling, activity, and potential impact; but it is

incomplete. Progress is hindered by continuing redefinition of its scope.

Element level models seem individually adequate but are decoupled from one another. Important models needed for later phases—such as surface- and space-based boost phase intercept (BPI)—are not now available, although some are being built.

Threat, phenomenology, and lethality models are flexible, but they lack data of the requisite fidelity in the regimes of interest for IDO and later phases. Some data such as hypervelocity impact in midcourse and boost cannot be measured in the laboratory or field and cannot be credibly deduced from system-level tests. Planned improvements will make data more accessible, but not necessarily more credible.

MDWAR – A Candidate System Level (End-to-End) Model

- Modern, object-oriented, event driven model architecture
  - Variable fidelity, messages, N-1 element simulations
  - Range of variable fidelity models
  - Causal for correct system delays
  - Insert hardware, models thru gateway—interfaced w/ MDSE
- Sensor models tested against other systems models
  - Not against detailed element models with some exceptions
  - Element program offices reluctant to provide representations for MDWAR or to support comparison of outputs
- Configuration control via complicated library
- Need to examine, in detail, how and when to incorporate needed extensions

MDWAR is a flexible, event-driven model with modern, object-oriented programming, in which events are modeled in a causal manner if the relevant system delays are specified correctly by the user. At present, MDWAR has important strengths and weaknesses. It has a range of models of sensors, interceptors, and communications of variable fidelity that seem adequate to provide element simulations of the components. Its suite of simplified radar and infrared sensor models have been tested against those in Extended Air Defense Simulation (EADSIM) and other systems models of similar fidelity and have produced reasonable agreement on detection, track, commit, and intercept times. However, these models have not been tested against detailed element models.

MDWAR explicitly treats actual tactical and strategic message formats. It treats their transmission, collisions, and delays stochastically. It allows for the federation of other communication models and hardware thru a flexible JRE-type gateway to federate with Missile Defense System Exerciser (MDSE) to support HWIL simulations.

MDWAR uses Ground-based Midcourse Defense (GMD)-supplied, pre-competitive fly-out tables for the ground-based

intercept (GBI) and exoatmospheric kill vehicle (EKV) whose grounding in and comparison with data is unclear. The treatment of communication, interceptors, and C2 is deficient.

Code versions and results are configuration controlled through a detailed library of code, input, and output conditions. This library could be used to transmit appropriate versions of MDWAR to users; but the current version is complicated, requiring about 800,000 inputs.

MDWAR uses the Jet Propulsion Laboratory (JPL)-developed SPEEDES operating system for distributed processing to achieve running times that are typically several times faster than real time to support man-in-the-loop simulations. SPEEDES is a flexible system that is appropriate for distributing processing over 10s of intermediate-level work stations. There are other ways of distributing such simulations over many and faster CPUs, some of them are compatible with JAVA and dynamic allocation. SPEEDES is not.

Some Needed Contributions to System Engineering

- Specification compliance issue
  - Adequacy of the baseline architecture to satisfy the system capability
- Sensitivity and breakpoint analysis
- Cost effectiveness trades
  - Tradeoffs between operational and system investments to minimize cost
  - The most cost effective flowdown and allocation of specifications
  - The point of diminishing returns for BMDS investment

MDA has identified the main areas where M&S needs to contribute more to systems engineering. The systems-level models now in development, particularly the extension of MDWAR to a C2/BM/C model, could address some of these needs, although missing models and lack of calibration currently undercuts their potential contribution. The models are not sufficiently tested to support sensitivity or breakpoint analyses or cost-effectiveness trades. The lack of key models for boost phase and discrimination limits their ability to guide investment planning or acquisition.

Findings

- Campaign & theater level models – CAPS and JWARS
  - Not linked to the models that need to provide the inputs
  - Of limited value for such purposes as offense/defense assessment and trade-offs
- There is a family of system level models capable of operating at various levels of fidelity
  - Models are redundant & decoupled
  - Not linked to element models
  - Element representations in these models are not provided by the element program offices
  - Validity and accreditation is less than robust
  - No evidence that M&S used in coherent fashion to support needs

Theater- (JWARS) and campaign-level (CAPS) models are over simplified and decoupled from system level and element models. CAPS and JWARS do not incorporate concepts of operations (CONOPS) which limits their utility for offense-defense and related policy tradeoffs.

The number of systems, mission, and force-on-force models appear redundant. Further, they are largely decoupled from element models. They are not fed properly from lower levels nor are they integrated between systems, mission, and force-on-force levels. They do not use lower level models provided or approved by the system program offices (SPOs).

As presently configured, M&S has little calibrated predictive capability. Thus, the activity serves more as an engineering adjunct than as a full M&S program. The Task Force found little evidence that M&S is being guided by or used to support either BMC or systems engineering priority programs.

Findings (cont.)

- MDWAR system level model
  - Adequate for NTB studies, training, & possibly system engineering
  - Lack of comparison w/ high fidelity models reduces confidence
  - Treats effects of potentially critical CEC data rate limitations with low fidelity lumped model approximation
    - Prevents analysis of CEC bandwidth limitation effects on other systems elements
  - Predictive capability limited by lack of models, calibration
  - Has not been provided to the user as a model of BMDS block performance
- Activity level effort is primarily in C2 and battle management
  - Incomplete and delayed by frequent changes in scope and priorities
  - Work on C2/BMC appears to be in conflict with analyses needed for confidence in performance of IDO

MDWAR seems adequate for the NTB studies and training simulations for which it was designed and possibly for some system engineering simulation use. Its flexible treatment of man-in-loop issues is useful in studying C2 for global Integrated Missile Defense (IMD). However, the lack of comparison of high fidelity element models with those in MDWAR for validation and accreditation reduces confidence in its results and utility.

MDWAR cannot treat cooperative engagement capability (CEC) rates other than via an effects (lumped) model and treats effects of potentially critical CEC data rate limitations with low fidelity lumped model approximation. It operates on a ~1 second time step. Hence, it cannot treat the kHz rates of CEC and advanced discrimination in a fundamental manner. Nor can it capture the impact of CEC and advanced discrimination bandwidth requirements.

MDWAR lacks comparisons and calibration for its current models and lacks fundamental models for BPI, forward observation, and advanced discrimination, which limits its predictive capability. However, with modest extension, it could adequately treat air-breathing threats, U.S. missiles, and offense-defense integration.

At the activity level, there is significant effort only in improved BMC, which is incomplete, delayed by shifting and *frequent changes in* scope and priorities, and has conflicting objectives for IDO.

Recommendations

- Modeling & simulation development and confident utilization need to be improved
  - Identify a system level deliverable which captures the operational effectiveness of all elements in a given Block and deliver it to USSTRATCOM to use in support of defense of the Regional Combatant Commands (RCCs)
  - Provide a truly independent (and consistent) source of verification, validation and (separately) accreditation for all models which feed into the systems level model
  - Integrate the now separate C2/BM/C and systems level approaches for model development into one model that assures a common architecture (and common M&S representation)

M&S development and product confidence need to be improved. The first step is to identify a system level deliverable that captures the operational effectiveness of all elements in a given block and provides it to USSTRATCOM to use in support of the relevant regional combatant commands (RCCs). A well-documented version of MDWAR that has carefully calibrated models for each of the elements to be delivered in each block could serve this need.

Careful calibration requires the development and use of a consistent and truly independent source of verification, validation, and accreditation for all models which are integrated into the systems-level models.

To have the maximum impact, the C2/BM/C and systems-level approaches need to be integrated in a common architecture and a common M&S representation. These efforts are currently almost completely separate.

Recommendations (cont.)

- Explore establishing a single systems-level model as the standard for integrated system performance assessment and trade-offs – MDWAR a likely choice
  - Require PMs to provide models or representations of their elements and components
    - With standard interface definitions, specifications, and controls
    - Accredited for specific, well defined purposes
  - Sort out the redundancies in systems-level models in use and development
  - Establish USSTRATCOM as a customer for the modeling and simulation (representing the RCCs) for the block system performance across the envelope

To realize the full potential of M&S—and to provide the forward-looking guidance for decisions the MDA needs—MDA should specify a systems-level model as the standard for integrated system performance assessment and trade-offs and enforce its use in decision making. MDWAR is presently the most likely choice. The goal should be to produce fixed software builds to specify Emergency Defensive Operations (EDO), IDO, and IMD blocks and provide them to the combatant commanders for assessment and training. The builds should then be updated with each hardware block and modification, specifying the capabilities of the current hardware. The foundation of this effort should be the development and use of a standard set of interface definitions, specifications, and controls.

MDA should require in contracts that SPOs provide models or representations of their elements and components accredited for specified purposes, after sorting out the redundancy issue in systems-level models in use and in development. It should then provide those models to USSTRATCOM (representing the RCCs) as a description of the block system performance across its expected engagement envelope.

Recommendations (cont.)

- MDA should
  - Assume responsibility for supporting core phenomenology and physics models
  - Add credible, higher fidelity representations of GBI discrimination and kill probability to the GMD system model
  - Incorporate boost phase intercept models (and spaced based elements, as they evolve) into the integrated systems simulation
  - Scope impact of high bandwidth CEC and advanced discrimination needs on simulations and predictions of system performance

To assure that M&S can satisfy both its diagnostic and predictive functions, MDA must assume direct responsibility for the needed supporting core phenomenology and physics models.
For M&S to be useful in guiding advanced data fusion and discrimination efforts, MDA must add credible, higher fidelity representations of ground-based intercept discrimination and kill probability to ground-based midcourse defense (GMD) system models.

To guide advanced technology efforts, MDA must incorporate boost phase intercept models (and spaced-based elements, as they evolve*)* into integrated systems simulations. The lack of this capability is impeding current attempts to evaluate the relative merits of various basing modes, define the initial capability levels desired, and assess their synergism with current midcourse systems.
In order to prevent the fragmentation of efforts at advanced fusion and discrimination, MDA must scope the impact of high-bandwidth CEC and advanced discrimination needs on simulations and determine whether they can be adequately modeled in current systems simulations such as MDWAR or whether they will require fundamentally new approaches.

CHAPTER 2. COMMUNICATION AND INTERFACE STANDARDS

Communications Challenges in BMDS Modeling and Simulation

Two Main Topical Areas

- Area 1: Modeling of communications networks and information exchange
  - Incorporating communications realism (finite bandwidth, latency, corruption, redundancy, disruption) to establish system level impacts of practical problems
    - "Facts of life" effects (weather, EMI, network node availability)
    - Inconsistent or erroneous implementation of standards
    - Defense suppression (e.g., denial of service attacks)
  - Key modeling and simulation issue for area 1: The implications of communications modeling on simulation architecture and run time
- Area 2: Federating specialized sims into an end-to-end engineering simulation
  - Making models of BMDS functions "communicate" with each other and operate causally to represent the detection-to-intercept engagement timeline
    - Matching "output pins" on one simulation to "input pins" on another simulation
    - Developing the ability to derive/validate timing & error budgets for BMDS engagement sequences
  - Key modeling and simulation issue for area 2: MDA simulations and simulation architectures capability to support end-to-end engineering analyses/verification

Communications – the physical transmission of information between nodes in a simulation and the more abstract relationship between models & simulations in an end-to-end federation (simulation of simulations) – plays an important role in the engineering of the Ballistic Missile Defense System and in the reliable assessment of BMDS capabilities. Communications plays a vital role in at least two ways.

The first is in the timeline realism that is introduced by modeling the system communications paths, attendant message flows, and message service delays. Getting the message traffic flow right – as well as the physics-based and human-in-the-loop events that trigger that flow – is a large step towards understanding the timeline impacts of what is often assumed away (or more positively, assumed to be working) in top-level architecture performance assessments. The main issue in this arena is the ability to incorporate

communications modeling *ex post facto* without having to pull the host simulation apart and without seriously impacting run time.

The second role of communications is as the linkage between models that might make up a federated end-to-end system engineering simulation. Such an end-to-end simulation would be potentially valuable for engineering design and verification of BMDS engagement sequences. Communications in this context applies to the ability of element (including C2/BM/C), component, and auxiliary models (such as, sensor energy management, data association, fusion, and tracking tools; common environmental and signature codes; test bed implementations of discrimination and decision algorithms) to signal each other and to act upon information passed with standardized message formats across standardized interfaces.

Though some models and simulations developed either at MDA or at the element program offices were conceived to communicate with a centralized executive over Distributed Interactive Simulation (DIS) or High Level Architecture (HLA) interfaces, others were not. Further, most were not designed to work with each other or to act on messages that reflect a network-centric fire-control approach. The main issue in this arena is the practicality of constructing engineering and verification tools that leverage significant investments at MDA in modeling and simulation. Clearly, an unattractive alternative would be to architect and build the required end-to-end simulation capability at MDA from the ground up.

Area 1: Findings

- There is a clear need for realistic communications modeling before the workability of message-intensive BMDS capabilities can be fully understood
  - Understand bandwidth constraints on performance of
    - Project Hercules Decision Architecture
    - Integrated Fire Control (Launch of Remote, Engage of Remote)
    - Target Object Map Transmission and Feature Aided Track Association
    - Plot Fusion (CEC-Like) and Network Based Discrimination
- Message-by-message modeling with queue management and node-by-node network modeling will throttle simulations designed for real time or faster than real time operation (e.g. wargaming applications)
  - Given current computing power at the JNIC
- Non-real time BMD system-level engineering simulations can handle almost arbitrary communications fidelity and should in the interest of grasping the difference between BMDS concepts and implementation

Transformational communications promises to eliminate network throughput and message service delays as BMDS issues. In the meantime, finite bandwidth communication pipes will be both an enabler of advanced BMDS concepts and a potentially powerful constraint on performance. Faithful modeling of communications is essential to understanding the difference between principles and real world practice.

Message intensive concepts like integrated fire control and data fusion are likely to preclude the explicit modeling of communications traffic in real time simulations used for CONOPS testing and operator training. On the other hand, design and verification simulations *can* and *should* attack the transmission and handling of information down to the bit level so that MDA engineers can get a handle on how communications—normally assumed to be what it must be in architecture-level analyses—modifies ideal BMDS performance.

Area 1: Recommendations

- Develop fast running effects models for real time simulations which still capture the impact of finite communications resources on BMDS operational flexibility and performance
- Federate or integrate realistic communications models with high fidelity system-level simulations used for engineering and verification analysis
  - Federate where possible with parts of existing codes
    - e.g., use EADTB for definitive Link-16 model
  - Initiate new communications modeling efforts to support detailed analyses of the new message intensive operational concepts

War gamers on consoles at the JNIC are not overly troubled by the details of networks and communications. On the other hand, they *are* interested in real time workloads and the relationship between the decisions they make and the BMDS behavior they get. Representation of communications throughput, network processing, and message latency are important to both cases. Real time functioning of war gaming simulations will require a fast running "effects model" of the communication system that distills the details into simple quality metrics and delays that still permit *bona fide* operational problems to be identified. Engineering design and verification simulations will require far more detail. In this case, real time operation is not the overriding concern. Federation with community standard communication models (e.g., Extended Air Defense Test Bed [EADTB] for Link-16) should be the first choice, with new models being built only as necessary.

Area 2: End-to-End Capabilities Sought

- A means to determine if all BMDS functions between detection and intercept can in truth be executed in the engagement time available
- A means of identifying all execution bottlenecks and failure modes that are not the result of accidents or poor quality control
- An end-to-end simulation capability that is functionally complete
  - Captures all the key factors in probability of engagement success (PES) chain
- A federated architecture that maximizes reuse of MDA core models and element simulations and that can accommodate new models over time
  - Element models and communications models
  - BMD Benchmark for tracking in multiple object environments
  - Hercules Test Bed for radar beam and energy management
  - Hercules Fusion Toolbox

MDA's need for an end-to-end engineering simulation capability is closely analogous to computer chip design and manufacture. A manufacturer wants to develop a new computer chip that will clock at speed X. The design team lays out the connections and logic gates and looks for some way to validate the logic before handing the blueprint over to the assembly line and committing to the expense of full-scale production. Will the chip *really* clock at speed X or is that just a drawing board fantasy?

The NTS needs to answer similar questions in the system engineering job, preferably in the design phase when mistakes are cheapest to fix and well before surprising behaviors are caught by big-ticket HWIL and live-fire demonstrations. The increasing complexity of BMDS interactions over time, and the genuine potential for unpredicted and unwelcome emergent behaviors, dictates the requirement for an exploratory simulation tool that is long overdue in its architecting and development. That same tool will also prove highly useful in the verification phase.

Emphasis on M&S federation and enforcement of communications standards recognizes that many of the piece-parts of a useful end-to-end system engineering capability already exist,

though they have not been developed from a master plan under centralized management. There should be no need to rebuild those tools. Likewise, new models must find an easy way to link into the end-to-end simulation framework as the BMDS evolves.

Area 2: Federation Issues With Ready Solutions Given A Well Thought Out Simulation Architecture

- Common bed down
  - Maintaining identical views of the battlefield between simulators
  - All element positions in one simulation must be the same in all other simulators
- Assigning executive authority
  - Accepting start and stop commands from alien simulations
- Execution speed
  - Real time to multiples (and sub-multiples) of real time
- Time synchronization
  - Measurement and control of time differences between simulators
- Environmental data exchange
  - Enforcing common threat and environment
  - Ensuring that when one sim affects the environment, all other sims know it
- Perceived data exchange, including tactical messaging system
  - Passing digital data to and from tactical battlefield messaging systems

Though conceptually powerful, M&S federation will require careful forethought. Enforcement of functional causality, time synchronization, common environments, messaging standards, and decision making protocols are clear challenges.

Area 2: Findings

- Enforcement of DIS and HLA interface standards means that any simulation could interact with another through a master simulation executive – in principle
- On the other hand, most missile defense models are not designed to communicate except in this most formal way – bits flow both ways, what about information?
  - Models for the most part not functionally specialized
  - Models not designed to plug into some overall intent
- Element models currently limited to tightly integrated representations of autonomous performance
  - Often, component (radar, C2/BM/C, interceptor) representations cannot be extracted
  - Messages may be passable across an interface from BMDS C2/BM/C, but wholly unusable
- Move towards integrated battle management and fire control (network centric warfare) will call for component models that can be individually signaled and manipulated
  - Models currently reflect the challenge of designing the actual BMDS

Though DIS and HLA standards are not mutually compatible, simulations written to either standard should be capable of plugging into a master simulation executive. For example, MDWAR has the capability to connect to any other simulation that can pass and receive messages over a standard communications interface. The ability to federate models through a central controller offers the potential for development of very powerful system engineering and verification tools that make full use of program office investments in high fidelity element representations.

However, the practical difficulty of constructing end-to-end simulations of the BMDS mirrors the difficulties of integrating and orchestrating missile defense elements in the real world. Models of legacy elements tend to be tightly integrated representations of autonomous performance and may be unresponsive, by design, to coordinating messages from C2/BM/C. Furthermore, as the BMDS moves towards more network centric fire control implementations such as launch on remote and engage on remote, there will a be a real appetite for sensor and weapon models that can be independently signaled and manipulated. Unfortunately, such stand-alone modules cannot be extracted from many of today’s element models which

were designed to simulate integrated element performance and not the detailed behavior of individual components.

Area 2: Findings (cont.)

- C2/BM/C and system engineering national teams both see need for end-to-end engineering design/verification tools and the need for a federation of interacting models
  - However, each are taking their own approach with little-to-no crosstalk
  - Performance certifications not likely to be in a common M&S frame of reference
- No end-to-end system engineering and verification tool exists today
  - Difficult to understand how BMDS could be put on alert without such a tool
  - Also not clear to everyone what the problem would be if that tool did not exist
- BMDS simulation design driven by a combination of past practice, service priorities, computer science, consensus, and happenstance
  - No engineering analysis plan against which M&S completeness could be judged
  - A framework of engagement sequences and event traces exists today that could drive modeling and simulation requirements and could establish relationships between models, but it is not being used that way yet to any effect

Both the NTS and the NTB are pursuing end-to-end simulation capabilities for their respective purposes, but they are not in meaningful communication with each other. This has resulted in parallel development paths and potentially serious disconnects.

There is presently no end-to-end engineering design and verification tool available, nor is there a clear recognition of the need for an associated development roadmap. Element model autonomy is an obstacle to the end-to-end simulation of BMDS capabilities. One could ask the question “How far beyond its design space could element X be pushed if interfaced to an integrated BMDS fire control and discrimination network?” However, the answer is presently outside the ability of MDA system engineers to address rigorously. Beyond that, stand-alone element models might be expected to accept network messages over an interface, but might also be expected to “drop on the floor” all messages it was not programmed to process.

Area 2: Findings (cont.)

- Communications between models is an ideal not implemented in practice
  - More than just the enforcement of communications standards
  - True model-to-model communications means the ability of each model to operate on information from the outside, implement decisions, and pass information back across an interface

The problem of federating models and simulations which were not designed to be interlocked, and which were constructed to no formal standards of fidelity, is a formidable challenge, though one worth taking on.

Area 2: Recommendations

- Develop functionally complete, end-to-end system engineering tools for detailed evaluation of event trace timing, validity, and error budgets
- Investigate move to a federated simulation architecture for high fidelity end-to-end engineering analysis
  - Maximize use of sunk MDA investments in specialized M&S
    - BMD Benchmark, Hercules Test Bed, BM/C3 Element Support Task (BEST), MDWAR, EADTB, element and component models
  - Accommodate upgrades without major recoding
- Add interoperability requirements to all existing system engineering contracts for development of BMD component-level models and include similar language in all future contracts
  - Define and enforce model communications standards
    - Move towards network centric warfare will drive emphasis towards signaling and manipulation of components (launchers, radars), not just elements

The recommendations are straightforward:

1. Develop an end-to-end system engineering tool for validation of BMDS engagement sequences and event traces. Such a tool is essential for understanding and allocating timing and error budgets end-to-end and for understanding, during the BMDS design phase, that concepts will really work as advertised.
2. So as to maximize the sunk cost investment in M&S at MDA, a federated approach should be investigated.
3. All future M&S development should be initiated with interoperability in mind to keep pace with evolving architectural concepts that stress true integration rather than the orchestration of elements originally designed for stand-alone operation.

CHAPTER 3. FIDELITY

Fidelity Needs and Issues

- The classes of MDA M&S activities examined range from phenomena to campaign - from constructive to live
- “Appropriate fidelity” is the minimum fidelity needed to answer the question being addressed
- The detail of parameter inputs should match the fidelity and application of model outputs
  - Detailed models can include hundreds of parameters
  - Parameters that drive models can be difficult to identify
  - Unknown sensitivity of simulation outputs to these parameters exists
  - A poorly estimated parameter makes it difficult to determine that the simulated results may be questionable

Global Fidelity Concerns by M&S Class

- Threat, engineering, phenomenology, and lethality models
  - e.g., Strategic Scene Generation Model (SSGM), BEST, Parametric Endo-Ex-lethality Simulation (PEELS), PEGEM….
  - Detailed simulations often founded upon uncertain or unavailable data
  - Nuclear environment not significantly addressed
- Element level models
  - e.g., THAAD, PAC3, GBM, Aegis, ABL, KE….
  - Class most likely to benefit from improved HWIL activity
  - Element contractors a key source of M&S data and resources
    - Level of involvement and coordination inadequate
  - BMDS HWIL evaluation models need to be well anchored via flight test
- Integrated system level MDA models
  - e.g., EADSIM, EADTB, MDSE, MDWAR….
  - Primarily computer/software and/or operator in the loop based
  - Currently focused on demonstrating connectivity – need to also be focused on developing architecture and systems
  - Element program involvement often uncoordinated

Observations with respect to M&S fidelity have been segregated into three general classes: phenomena modeling, element modeling, and integrated element or core modeling.

SSGM, BEST, PEELS, and PEGEM are representative of the phenomena class of M&S. This class encompasses underlying threat characteristics, environment, and lethality models used to develop the BMDS. The primary overall concern with respect to this class is the appropriateness, value, and utility of the underlying database of measurements used to anchor the models. Additionally no clear position has been taken with respect to including a nuclear environment into the BMDS.

THAAD, PAC-3, GMD, ABL, and Kinetic Interceptors (KI) modeling activities are representative of the element class of M&S. The primary concern with respect to this class of M&S is the role and the level of hardware inclusiveness that HWIL simulators are playing in the BMDS development. Additionally, roles and responsibilities among the various participants in this area are not always clear.

EADSIM, EADTB, MDSE, and MDWAR are representative of the integrated element or core class of M&S. The relative importance and the roles of commander-in-the-loop, operator-in-the-loop, and hardware-in-the-loop activities and how these activities are balanced is an area of concern. Additionally, the purpose for which these M&S activities have been developed and how they are employed needs to be balanced between competing evaluation and architectural design objectives.

Some Continuing Systemic M&S Fidelity and Associated VV&A Challenges

- Technical
  - Demands of hard-to-kill (HTK) end game require a higher level of fidelity in the ground simulations (both digital and hardware-in-the-loop (HWIL)) (Independent Review Team (IRT) 98)
- Programmatic
  - Accelerate the upgrade of a HWIL facility adequate for credible testing of the EKV in a variety of endgame geometries against a variety of threats (IRT 99)
  - Vital information needed for development and decisions will come from simulations / HWIL anchored with flight test data (IRT 1999)
  - VV&A as presently practiced with respect to M&S techniques is not sufficiently disciplined to inspire confidence in their use in T&E (DSB 1999)
  - The task force determined that the majority of problems associated with DoD software development are a result of undisciplined execution (DSB 2000a)
- Fiscal
  - More investment needed in conceptual modeling, phenomenology, and experimentation to gather realistic input data in order to provide decision makers with confidence in M&S results (DSB 1999)

Many of the current fidelity concerns have been observed and identified during prior M&S program reviews and remain relevant today. In part it was the existence of these systemic issues that became the rational for establishing a coordinated M&S program. Such legacy factors continue to limit the M&S program in achieving its full potential and value.

M&S Fidelity Metrics

- Miss distance was traditionally the standard metric for MDA M&S fidelity
- HTK as a concept has been verified by flight experiment
  - There will never be sufficient resources for flight testing alone to provide confidence in the BMDS across the full envelope of operations
  - M&S at any level will use less resources than live flight testing
  - M&S is the only viable means to explore additional HTK capability space
- Conventional wisdom
  - HTK thought to require high fidelity modeling of every nuance in order to faithfully evaluate miss distance
- Less often appreciated
  - An interceptor sensitive to every nuance is poorly designed
  - The impact of uncertainty and the buildup of consequences
  - The threat will never be understood to a comparable degree of accuracy
- The most important factor in HTK capability evaluation at the intercept envelope edges will be HWIL testing of acceptable fidelity

The traditional metric for missile defense has been its ability to faithfully model "hit-to-kill" (HTK) engagements. This metric can serve as a basis for defining the issues as well as for providing motivation when addressing missile defense M&S fidelity. Although HTK has been verified as a concept, the expense associated with flight tests are such that there will never be sufficient resources to either obtain quality statistical data about any single flight construct or to address performance at the edge of the capability envelope.

Both an understanding of the threat and of interceptor performance is critical for a successful HTK. Yet, in the real world, the threat will never be understood to the degree preferred. A HTK paradox is that a well-understood threat, or assuming a well-understood threat, can result in a fragile design whereas a poorly understood threat can result in a robust design.

The principal mechanism available to understand overall missile defense performance, within realistic economic constraints, is through the use of "hardware-in-the-loop" testing.

Hardware-in-the-Loop Simulation

- Current Kill Vehicle (KV) HWIL fidelity demand concentrates on the seeker
  - HWIL seeker with synthetic imaging
  - Other factors: HWIL needs to address missile body, IMU, controls, valves, etc.
  - Subtle integration errors potentially missed
- Expensive to obtain high fidelity in an integrated system but cost is still lower than flight testing
  - Test limitations may make flight testing less valid at the system level than the right level of HWIL testing
- Current HWIL testing tends to involve hardware that is either convenient or pushing the state-of-the-art rather than what is required or appropriate
- Relative roles and responsibilities with respect to Element Programs, Service's and MDA were not clearly defined

While HWIL testing can be expensive, its costs are likely to be modest compared to flight testing. The Task Force found that some tested HWIL assemblies are not as inclusive as they might be with respect to the actual flight hardware.

Most HWIL interceptor simulations are focused on evaluation of the seeker, associated processors, and related algorithms. This is not surprising as the seeker is a critical component. Equally important however is the remainder of the interceptor including its more basic components such as inertial measurement unit (IMU), controls, valves, and functional responses such as missile body flexure dynamics. Typically these other factors, even when included, are not fully incorporated into the HWIL.

Some hardware often is only bench mounted and not subjected to the dynamic environment necessary to be realistically exercised and, as a result, subtle integration errors can be missed. There have been exceptions to this HWIL testing observation, such as hover tests, or combined synthetic target generation full up dynamic table tests of more complete versions of the test article. However, such higher quality HWIL testing remains the exception rather than the rule. At the element level the critical source of HWIL data, hardware, and

testing capability resides with the major defense acquisition programs (MDAP's). However the relative roles and responsibilities between the MDAPs, the Services, and MDA remain unclear.

The Impact of Uncertainty

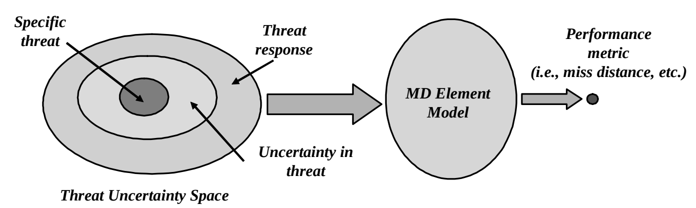
- Uncertainty in M&S fidelity is the difference between "idealized behavior" and reality considering the element model, the threat, and the required performance
- Uncertainty in fidelity is addressed through sensitivity analysis across the full range of the uncertainty
  - Identifies what has to be modeled at what level of fidelity
- Earlier DSB report recommendations remain relevant
  - Traditionally what is well understood (i.e., the environment) is modeled at high levels of fidelity regardless of the sensitivity of the result to the phenomena
  - Conversely what is not well understood is modeled simplistically regardless of its importance
- BMDS system design
  - Assuming a well defined threat can lead to a brittle system design
  - Recognizing the inherent uncertainty leads to a robust system design
- Significant MD threat uncertainty exists due to
  - Lack of intelligence data
  - Manufacturing realities
  - Threat responses

Uncertainty, that is the difference between reality and the model, plays a critical role in understanding M&S fidelity. One objective of sensitivity analysis is to ensure that those parameters that have the most impact on the simulation performance are accounted for during model development in proportion to their importance. An earlier DSB report found that often what is well understood (for example the environment) is modeled more extensively (consequently employing more resources) than that which is not well understood, regardless of its relative importance to overall simulation performance. This is an example of parameter uncertainty and sensitivity analysis being improperly applied to missile defense M&S.

Of singular importance to the current M&S fidelity issue is the observation that there will always be uncertainty associated with the threat, either because of a lack of intelligence data, because of manufacturing uncertainties, or because of deliberate uncertainties introduced by the potential enemy. This reality establishes a limit to the value of certain modeling parameters.

Threat Modeling

- BEST is the principal high fidelity M&S activity associated with threat signature development
  - Brings code languages up to date
  - Replicates existing physics code (OSC, XPATCH, etc.)
- The level of fidelity has probably reached the point of diminishing returns
  - Further fidelity of threat signature modeling unlikely to benefit BMDS
    - If assumed representative may be counterproductive
    - An example is early conclusions reached about midcourse discrimination capability via EO/IR observations
- Lethality modeling fidelity suffers from a similar deficiency
  - An exception is hypervelocity phenomena - unavailable via ground test
- Sensitivity to input assumptions is a critical modeling result



BEST is the acronym for current M&S activity associated with phenomena development involving the electro-optic (EO) and radio frequency (RF) characteristics of the environment and threat signature. BEST brings existing code such as OSC and XPATCH up to date and incorporates this code into a common framework. With respect to midcourse, at least, this activity has probably reached the point of diminishing returns. That is, the level of modeling detail has reached that point where it exceeds the expected threat uncertainty.

This situation is illustrated in the accompanying figure which represents how the threat characteristics are mapped by the element model to the desired response. Significant activity has been expended in characterizing the threat to a level of detail that will provide the desired performance; for example, an acceptable miss distance. However the uncertainty associated with the threat generally exceeds the actual modeled detail signature of the threat. The most robust missile defense design is one that will provide acceptable performance, given the more realistic uncertainties expected. Modeling the system with tighter threat parameters can produce overconfidence and may be counterproductive.

A similar, but less serious, situation exists in the lethality area where uncertainty in the threat becomes a basis for modeling and for drawing conclusions about performance. However, in this case, there is little reliable data on hypervelocity impacts and the associated models are poorly anchored in that regard. Activity to anchor such models should continue as, and if, such data becomes available.

BMDS System Level Modeling

- Fidelity at any particular level of the BMDS hierarchy will depend upon the problem to be addressed at each level, not on the level itself
- Higher level (i.e., cookie cutter, etc.) solutions generally assume the answer will be decoupled from other program inputs
  - Not clear decoupling assumptions are valid in current models
- Focus of higher level modeling fidelity has been on interoperability, communications, and CONOPS development
- There appears to be no current M&S tool of appropriate fidelity for future block architecture development
  - Of equal importance to current objectives
  - Needs to be considered and designed into developing models
  - Unclear that NTB and NTS M&S objectives are in agreement

It is often implied that M&S fidelity increases as model detail is added to those simulation levels closer to the individual hardware components and decreases as modeling is aggregated to higher levels. While the accuracy may increase with model detail, fidelity might not. Aggregation to higher missile defense levels takes many forms and the actual level of fidelity achieved will depend on the question being asked and the purpose for which the model was developed.

Higher level system simulations generally assume that the answer will be decoupled from other program inputs, yet it is not clear that decoupling is valid in current models. These effects are discovered only by applying end-to-end engagement simulations, where statistical performance is assessed by Monte Carlo iterations of the entire set of coupled processes.

Examining the higher level, or core missile defense models, it is clear that the primary program focus in this area has been on the interoperability, communications, and CONOPS functions. Although several models were available that could contribute to developing and evaluating future block architectures, no higher level M&S tool

was found that was available to uniquely perform this critical function.

Flight Testing and Model Anchoring

- Flight test flexibility will always be limited
  - Cost and schedule constraints
  - Need to demonstrate progress
  - Safety and range capabilities
- Objectives of flight testing
  - To provide proof of concept
  - To support the acquisition process
  - To verify the BMDS model
- The objective determines those flight constructs selected and fidelity of the model anchoring
  - Examining system capabilities at the edge of the performance envelope requires extending flight test data into new regimes, with associated risks
  - Interpolation vs extrapolation will be a factor in construct selection
- Focus should be on operational system risk management not flight test risk management
  - If flight testing is dominated by need for success, then we will not find out what we don't know
  - Structure flight test program to support BMDS modeling objectives

Linking simulations and models to real world performance is critical for fidelity. The ultimate linkage is by way of a full up flight test program to anchor the BMDS system model. Such testing is a complicated process that will always be limited by a variety of constraints. An important question to address is the objective of such a flight test program. One purpose of a flight test program is to provide a means to manage operational system risk.

Since there will never be sufficient flight tests to fully characterize the BMDS within its operational space, and certainly not at the performance envelope edges, flight tests should be constructed with emphasis on model verification as a goal, as well as to verify operational issues. Focusing on BMDS model verification and selecting flight test constructs with this as one objective can increase risk. However, data resulting from a broader test spectrum will enhance confidence in the M&S program to predict performance for the BMDS across a broader spectrum of capabilities.

Findings

- The fidelity of the threat signature models for midcourse are probably at the point of diminishing returns with the exception of:
  - Lethality anchoring data (e.g., hypervelocity KKV data)
  - "Advanced Discrimination" and "Forward Based Sensing" approaches that do not rely on detailed "a priori" data
- Element HWIL models with appropriate fidelity important to explore capabilities not amenable to flight test
  - HWIL can and should be exercised at a higher level of integration than just the seeker and associated algorithms
  - Consider structuring flight tests to also support model validation into areas of new capability
  - Manage operational system risk rather than flight test risk

There are three primary conclusions that can be drawn from the previous analysis of fidelity, one for each class of M&S: phenomena, element level, and core or integrated element modeling.

With the possible exception of hypervelocity lethality, threat signature, and phenomena modeling of exoatmospheric engagements, the fidelity of the threat signature models for midcourse is close to the point of diminishing returns and resources might be adjusted accordingly.

Increasing the level of HWIL M&S activity along with an increase in the associated degree of hardware involvement for the element level programs is important to explore system capabilities at the envelope edges. The flight test program should be structured with model verification as one primary objective, in addition to its other program objectives.

Integrated element or core model development should address architecture and block change development as well as interconnectivity. There is no dedicated BMDS architecture model capable of evaluating block change alternatives, including a common set of metrics for such decision making purposes.

Recommendations – Threat Phenomena and Environmental Fidelity

- Threat phenomena modeling fidelity
  - Consider limiting further expenditure of resources in those areas of M&S associated with detailed payload threat signature development for midcourse
  - Conserve related resources associated with the gathering, exploitation, testing, measurement, and verification of such detailed payload threat signatures
  - Continue to obtain data for M&S purposes via intelligence and surrogate means as related to the threat and associated delivery capabilities
  - Exploit prior signature development programs by fully reducing already available data (e.g., MSX)
- Environmental modeling fidelity
  - Model environmental details at a level of fidelity consistent with their expected marginal contribution to the BMDS effectiveness
  - Establish a corporate position with respect to including nuclear effects in the BMDS modeling and simulation

With respect to the threat and phenomena areas, a primary recommendation is that MDA consider limiting additional resource expenditures associated with highly detailed threat signature development normally associated with midcourse. Data associated with advanced discrimination techniques which are not "a priori" dependent should continue to be obtained. Such a recommendation would also be applicable to those supporting functions associated with the gathering, measurement, and verification of such detailed exoatmospheric data. Threat capability data should continue to be obtained, modeled, and existing data sources such as Midcourse Space Experiment (MSX) should be exploited.

MDA should establish a corporate position with respect to the inclusion of nuclear effects globally into the BMDS program. The importance of sensitivity analysis and its role with respect to environmental phenomena code development needs to be emphasized.

Recommendations – Lethality Fidelity

- The fidelity of PEELS has probably reached the point of diminishing returns
  - Consider limiting further resource expenditures for lethality M&S activities which are highly dependent upon threat payload design details
  - Utilize hypervelocity flight test data, when it becomes available, to anchor exoatmospheric lethality models
  - Continue M&S development activities with respect to the impact of the threat intercept/detonation effects

Also, consider limiting additional resources associated with lethality modeling effects that may be unrealistically dependent upon threat design details, with the exception of anchoring hypervelocity impact models as, and if, relevant data becomes available.

Recommendations – Element Fidelity

- Improve the general level of fidelity for "hardware-in-the-loop" testing of all BMDS elements
  - Expand the role of HWIL within the BMDS development and its elements
  - Incorporate feasible hardware components and operational software into HWIL simulations
- Harmonize flight test activities, exercises, wargames, and M&S program objectives to enhance confidence in BMDS model fidelity
  - Jointly develop flight test constructs that support both the demonstration of the BMDS effectiveness as well as the extrapolation of its performance via M&S
  - Consider developing flight test scenarios based upon their value in calibrating the M&S toolset at the design envelope edges
  - Expand flight performance statistical database and examine higher risk "off nominal" operations using enhanced HWIL capabilities

With respect to fidelity at the element level, the general role of HWIL and its associated degree of hardware inclusion should be elevated to provide for greater confidence in the corresponding statistical database generated as well as for performance excursions into flight regions not addressable in the flight test program. HWIL components should be as close to the flight configuration as possible, including realistic dynamics as applicable. Most current HWIL simulations are primarily centered on the seeker and its associated algorithms.

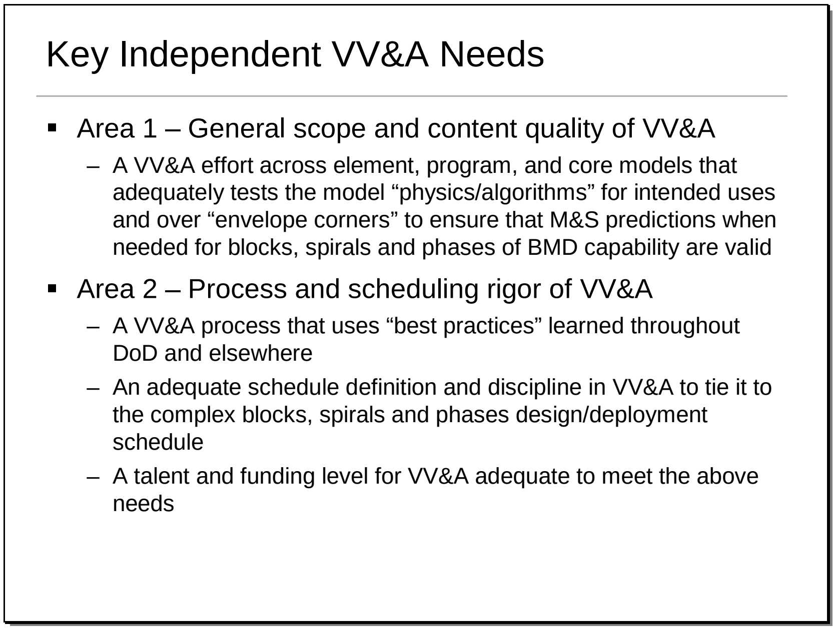
Developing flight test constructs should be a joint activity between the element program office, test and evaluation, and the M&S program office. M&S should not be a passive participant in the flight test program but should have an active role in the development of flight test scenarios, structured specifically to enhance the fidelity and ability of the BMDS simulations to extend into unexplored regions with confidence.

CHAPTER 4. ENSURING THE VALIDITY OF SIMULATIONS

Selected Definitions

- INDEPENDENT – A knowledgeable and experienced capability not involved in the design or development of a model
- VERIFICATION – The process of determining that a model implementation accurately represents the developer's conceptual description and specifications. Verifications also evaluates the extent to which the model or simulation has been developed using sound and established software engineering techniques.
- VALIDATION – The process of determining the degree to which a model is an accurate representation of the real-world from the perspective of the intended uses of the model.
- ACCREDITATION – The official determination that a model or simulation is acceptable for use for a specific purpose.
- BASIS OF CONFIDENCE (BOC) Document – A document that identifies the functionality and limitations of a model and provides a summary and reference of VV&A activities. The BOC is typically used to support accreditation or use decisions.

As noted on this chart, independent verification is the process of determining that a model implementation accurately represents the developer's conceptual description and specifications. Verification also evaluates the extent to which the model or simulation has been developed using sound and established software engineering techniques. Validation refers to the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model. Accreditation is the official certification that the model or simulation is acceptable for use for a specific purpose. The Basis of Confidence documents are used to record the functionality and limitations of models and will be discussed later in this section.



The DSB examination addressed two inter-related fundamentals of VV&A. The first is ensuring adequacy and completeness of the technical aspects of the models. Are the underlying physics, algorithms, and engineering representations adequately checked? The second area is the maintenance of uniform process and documentation. Does VV&A employ best practices, have adequate definition and discipline, and involve acceptance by those responsible for the performance of the elements and systems being modeled? Is the process adequately synchronized to the blocks, spirals, and phases of the MDA development and deployment schedule? For both of these basic areas, a corollary consideration relates to levels of talent and funding available to implement the VV&A process. Another corollary involves "buy-in" to the VV&A process by all element program managers, Service operators, war gamers, and other stakeholders.

During the study, much VV&A information from MDA was received in the (archived) presentations to plenary sessions. One additional splinter session was held on May 19, 2003, to specifically discuss VV&A activity with MDA M&S managers. This session was

particularly beneficial for examining and discussing some of the documentation which time would not have otherwise permitted.

The overall summary observation reported to the full Task Force following this splinter meeting, and reflected in what follows in this section, was that further confidence was gained in the existence of an aggressive MDA process to establish and maintain VV&A rigor, to include filling in past gaps. The hard, detailed effort to fully synchronize VV&A to the various blocks, spirals, and phases remains to be completed.

VV&A Repository

- Need: A comprehensive web-based VV&A repository with secure access to VV&A documentation and track VV&A activities
- Recommended approach: improve current system with collaboration tools
- Current status
  - Hosted at the JNIC / IDC
  - Researched site enhancement requirements and identified possible software solutions
  - Evaluating alternative hosting sites
- Issues
  - Information assurance, security, and need to know
  - JNIC / IDC need to accelerate updating site

This chart summarizes an approach to establish a comprehensive and accessible archive for all model VV&A documentation. The Task Force strongly favors this effort.

Findings

- The credibility of models is mixed
  - There is no consistent verification, validation and accreditation process across MDA M&S development
  - The Aegis, PAC-3, and THAAD models are generally carefully validated for the purposes for which they are accredited
  - The GMD model treats some critical parameters such as discrimination and overall probability of kill too simplistically for adequate credibility
    - Sensitivity to uncertain parameters remains a key issue requiring systematic treatment and reporting
  - The ABL model departs from the use of variable fidelity representations to federate the ABL battle manager directly
  - There is no usable model for boost phase intercept systems
  - No useable models for space based kinetic interceptors or sensors nor space based DEW elements were identified

PAC-3, THAAD, GMD, Aegis, Airborne Laser (ABL) models seem adequate for their intended uses, for which they have been carefully accredited, but they are decoupled from each other and from the system & activity layers of the M&S pyramid. GMD model treatments of discrimination and kill probability are oversimplified and do not provide confidence in sensitivity assessments. The ABL model just federates its battle manager. There are no useful models for boost phase kinetic or directed energy intercept from the surface or space.

Current background, target, and lethality models are being integrated into a modern package, which will make the data more readily available to users. However, the impact of this effort is likely to be limited because the current element models embed those data packages. The new products appear to be useful primarily to kinetic interceptors (KI), for which no system level model is being built. A fundamental limit is the lack of data at appropriate hypervelocity closing velocities with large masses, which cannot be addressed through laboratory or ground tests. Thus, ongoing efforts will make the data more accessible, but not more credible.

Findings (cont.)

- IV&V (and A) needs to go well beyond “business as usual”
  - The credibility of the BMD system performance will be uniquely dependent on the credibility of the M&S insight
  - Need assurance that projections inferred represent the best insight that can be offered
- Peer review by “outsiders” is required to assure the fidelity of the scientific and engineering representations
  - Not currently accomplished consistently across the program
- The Nuclear Quality Assurance (NQA) approach may be required to document all scientific and engineering M&S representations and to enable traceable configuration control

A key element of configuration control is independent verification and validation (IV & V) (and accreditation [A]). The Capability Maturity Model (CMM) level designation provides a measure of the maturity and discipline inherent in a software development team. The nuclear reactor community (submarine and civilian) has a rigid nuclear quality assurance NQA regimen. All calculations are documented in scientific notebooks; all are checked. Use of unchecked calculations or codes is simply not permitted. This regimen, foreign to MDA, would introduce immediate configuration control for spiral development and block change. In addition, it would facilitate IV&V and accreditation processes.

Findings (cont.)

- Area 1 – general scope and content quality of VV&A
  - The MDA VV&A process has trended over several years (since SDI) from "head to head" comparison of parallel models toward use of fewer models, each checked by a relatively smaller "associated but independent" VV&A effort
  - The impact of this trend will increase beyond Block 04 as fewer of the key models have benefited from parallel comparison
- Area 2 – process and scheduling rigor of VV&A
  - MDA has substantially increased emphasis on M&S VV&A processes
    - Importance of incorporating and maintaining established software practices including VV&A reflected by management personnel qualifications, M&S directives and VV&A program content
  - However, diversity of VV&A process description details by the element, program and core VV&A presentations raises concern
  - Proprietary M&S codes must not be permitted to impede IVV&A
- Overall, VV&A comprises ~10-15% of total M&S funding

Regarding the general method by which missile defense VV&A seeks to ensure M&S physics and algorithm quality, area one in the discussion above, the Task Force observes the following trend. In earlier years it was common practice to develop and compare multiple and largely independent models. Such "parallel" models may have initially incorporated their own sets of implicit and explicit assumptions, but final results were vetted by give and take among multiple M&S development teams expert in the phenomenology, physics, and engineering areas involved. This practice has generally given way to one in which significantly fewer core and element models are relied upon for predicting performance parameters. VV&A is now generally performed by a number of comparatively small groups, one being assigned to each major model. Whether or not this situation is sufficient to ensure M&S content quality as overall BMDS complexity increases beyond Block 04 will be further discussed below.

With regard to VV&A process specification, configuration control, and scheduling rigor, area two discussed above, the Task Force observes a substantial increase in emphasis by MDA over the past two years, particularly following release of the Weyant M&S report. The positive steps taken include addition of management personnel

well versed in software processes including VV&A. Also encouraging is the VV&A direction contained recently revised M&S policy. However, from the briefings received it is also observed that improvements in policy have not yet fully translated to uniform VV&A process description and practices across all the element and core models. Accreditation status and currency is also not yet uniform; within a single simulation it is common to find some models accredited and some not. The fact that some key models are held as proprietary to their developers was noted, although it is not clear whether or not this creates any impediments to the VV&A process.

Lastly, it was observed that the appropriate level of resources currently being allocated to VV&A represents 10-15 percent of the amount dedicated to M&S overall.

Findings – Area 1
General Scope and Content Quality of VV&A

- For Block 04, non-C2/BM/C VV&A is generally sufficient, largely owing to long maturation of key models, although some aspects, e.g., track redundancy and cuing, warrant particularly close continued VV&A attention
- For Block 04, VV&A for any required new C2/BM/C M&S efforts are particularly hard pressed by the deployment schedule
- For blocks beyond 04, current VV&A of "physics/algorithms" M&S critical to prediction of future element and associated architecture performance may be insufficient, e.g., KI and/or SSTS
- Level of VV&A for blocks beyond 04 should reflect increasing BMDS and associated M&S complexity, particularly in the C2/BM/C area; IVV&A level of support may be insufficient to do so

The IVV&A-related conclusions may be categorized into the same areas discussed above. For area one, dealing with the M&S technical quality, the Task Force concludes that Block 04 models, with the notable exceptions of those for C2/BM/C and perhaps multi-element functions such as track correlation and weapon cuing, have effectively been verified and validated for their intended Block 04 uses. These models benefit from much prior use and a generally greater degree of cross checking with parallel models – in some cases going back for decades.

This general endorsement does not apply to the C2/BM/C area, however. In that area, there is a concern that time is very short to perform IVV&A for new models such as MDWAR sufficient to reliably predict system capabilities and limitations. (Although the Block 04 *element* models are generally sufficient to address a wide variety of questions, it is impossible to anticipate in advance all element interactions; because of this, it is important to review carefully the *core* models for each use in making program decisions.)

Beyond Block 04, there are additional difficulties. Many future system elements—such as KI and SSTS—are still at immature levels of development, use, and VV&A. This conclusion extends to a

particularly serious concern in the case of C2/BM/C models for future blocks, where increasingly numerous systems interactions imply increasingly complex VV&A. Reliable C2/BM/C modeling is required sooner, not later, to optimize future block architectures and designs taking full account of threat and countermeasure spectra.

Findings – Area 2
Process and Scheduling of VV&A

- Additional M&S policy and directives (post 2000), along with strong management/staff M&S procedural competency, is making positive impact on VV&A process/control rigor and uniformity
- No master "accreditation tree" with clearly delineated buyoff (and buyoff recommendation) dates by M&S users, including the two national teams, for blocks/ spirals/ phases, is currently approved (although aspects are in work). Such a document would help tie VV&A to the complex BMDS design/deployment process and prevent M&S "escapes"

Overall, given the architectural, technological and operational complexities of BMDS, a VV&A level of effort of ~10-15% of total M&S (characteristic of M&S for much less complex systems) should be closely examined for sufficiency.

Turning to area two, VV&A process management, the Task Force first concludes that M&S policy and directives issued after 2000, along with added staff M&S procedural competency, is making a positive impact on VV&A process and control rigor and uniformity. (For example, the basis of confidence documents now being developed for the element and core simulations provide good documented support for the approval of models; their use is encouraged.) However, accreditation (participation, uniformity, tracking, and synchronization to development/deployment schedules) is found to be an area for improvement. An accreditation tree incorporating more detailed planning, wider distribution for feedback, and regular updating is thus recommended below.

It is important that the system element material developers assume a stake in the models used to represent the system elements developed under their authority. The material developers, the PMs, their staff, and their contractors, are most familiar with the details of their system. They are most familiar with the key engineering aspects of their systems, and they will know the sources of error and imperfection. They will be also able to provide informed judgments regarding degree of abstraction uncertainty and are likely to know about the idiosyncrasies of their system. Additional M&S policies

and managerial directives are anticipated to make a positive impact on needed participation in accreditation.

A final conclusion that overarches both the technical quality and the process management areas is that, given the architectural, technological, and operational complexities of BMDS, a VV&A level of effort of ~10-15 percent of total M&S (characteristic of M&S for much less complex systems) should be closely examined for sufficiency. (This statement may apply to VV&A of operational codes, but these were not examined by the Task Force.)

Recommendations

- Form an IVV&A Quality Assessment/Audit Team with a balance of experienced MD element algorithm, C2/BM/C and software experts, as well as representatives from the M&S user and MD operator communities
  - Report directly to MDA M&S management to identify any escapes in IVV&A uniform technical quality and standard process compliance
  - Critique IVV&A milestone dates in view of block development schedules
  - Make recommendation on all accreditations
  - Coordinated with, but smaller than and independent of current M&S IPT

Based on the above considerations, findings, and conclusions, the DSB Task Force has formulated four recommendations in the area of VV&A. The first two are aimed at ensuring the technical quality of the VV&A process; the latter two deal with process and funding concerns.

A relatively small standing assessment/audit team should report directly to senior MDA M&S management to identify any escapes in VV&A uniform technical quality and process compliance, and would augment the strong process orientation of the current management team. This team should critique VV&A milestone dates in view of the block development schedules and help to harmonize the technical status of the models with the need dates. It is further suggested that this team make recommendations on future accreditations. The team would coordinate with and not take the place of the larger M&S Integrated Product Team (IPT) currently in place.

Recommendations (cont.)

- Further refine and document IVV&A strategy to ensure M&S validity to the many “envelope corners” of global multi-tiered BMD
  - Pay attention to what is not included in the models, to what is assumed to work perfectly, and to the sensitivity of the results to uncertain input parameters
  - “Break the codes” in as many ways as possible (a few examples - ROEs, shot correlation, penaids, track branching, ….)
  - Expand “threads” strategy to check all functionality of all models
  - IVV&A the data catalogs for all models to ensure that key variances and other statistics are recorded and tracked

This recommendation is to help ensure that M&S can stand as a principal source of confidence in the missile defense systems performance over the entire range of expected operating conditions. VV&A must identify what gaps exist in the models as well as what is being erroneously assumed to work perfectly. The strategy should be to “break the codes” in as many ways as possible.

Examples of this strategy include testing the models under multiple threat-defense geometry and saturation scenarios and under various countermeasure, shot-to-shot correlation, and track branching conditions. One relatively standard tool that the strategy should consider is the use of carefully designed code testing “threads” to stress all code functionality. In addition, it is important that the VV&A process examine the parametric data used in all models with regard to accuracy and completeness, as well as include all variances necessary for purposes such as Monte Carlo runs. The mechanisms for updating and tracking parameter and variance values based on hardware testing should also be included.

Recommendations (cont.)

- Develop, or accelerate development of, accreditation tree for all models, but especially for higher level models, that addresses previously stated concerns. Approvals should probably include that of NTS, and perhaps NTB, but should definitely culminate at a higher government level
- MDA should review IVV&A total level of effort to ensure that it supports the complexity level and criticality of the M&S effort (to address previously stated observation and conclusion points)

Accreditation sign-offs would likely include that of NTS and perhaps NTB, but should definitely culminate at a higher government level. This process recommendation is aimed at establishing better uniformity and tracking of all M&S verification and validity responsibilities and current/projected status. While the VV&A material presented in MDA's briefings during this Task Force study did indicate that there was an accreditation process extant for each model, these separate accreditation processes did not appear to be extremely uniform with clear-cut responsibilities, sequencing, and stakeholder participation. The Task Force views this recommendation as a way of extending further the existing positive trend toward highest quality VV&A process and metrics.

While the Task Force did not review VV&A funding in depth, this recommendation stems mainly from the previously discussed observation that MDA VV&A levels, compared to the levels of the supported M&S, appear to be comparable to VV&A levels for many less complex and less critical (than missile defense) DoD systems.

Finally, while not a formal recommendation, it is suggested that MDA discuss VV&A strategy and tactics with both government and integration contractor VV&A personnel associated with the Navy

Aegis program. Aegis is a highly complex system with many M&S parallels to ballistic missile defense. A brief teleconference with M&S experts at the integration contractor indicated VV&A for the many Aegis models was headed by the Navy (at Dahlgren) for U.S. operational ships, and by the integration contractor (at Moorestown) for foreign sales ships. Both structures seem to work well, but more importantly there appear to be lessons learned of use to MDA in both locations.

Recommendations (cont.)

- MDA should assess the peer review approach used by the DOE Labs as a basis for establishing a model for the FFRDCs to make a value added contribution as a source of IV&V and accreditation
  - Depending upon the results of the assessment (conducted by an independent review team), MDA should then select and implement a FORMAL configuration control and IVV&A approach

Independent review is an important aspect of adequate VV&A. Peer review is used effectively for this purpose in the Department of Energy (DOE) laboratory system. While there is no complete analog available to MDA, it may be that one or more Federally Funded Research and Development Centers (FFRDCs) could fill that role. MDA should evaluate the potential value of such an approach.

CHAPTER 5. ADDITIONAL OPPORTUNITIES FOR M&S CONTRIBUTION

The Task Force recognized that additional opportunities exist for modeling and simulation in the development, deployment, and preparation to operate a ballistic missile defense system. As a consequence, issues beyond the scope, breadth, fidelity, element "communication," and verification were considered.

Findings – Scope and Integration

- Opportunity exists to provide M&S support to:
  - Develop the defined Block of capability and to evaluate and assess its component, element, and integrated system performance
  - Explore trade-offs for evolution towards the end capability – an integrated missile defense to defeat missiles of all ranges in all phases of flight
- Current M&S directed at supporting 1, but:
  - Current system level architecture approaches rely primarily on kinematic analyses at the element level
  - Integrated system level M&S needs to offer the capability to assess the merits of integrating land, sea, and space based resources
  - The need to assess advantages of true system-level integration or true fusion of resources has not been adequately served by separate, and often uncoordinated, systems level and C2/BM/C M&S efforts

MDA tends to rely on modeling and simulation as a "tool" and views M&S from a variety of perspectives as part of the cost of doing business. The opportunity exists to provide coherence and rigor to the M&S process across MDA and to now use credible, independently verified and accredited M&S techniques to:

1. Evaluate the capabilities (needed) for each element of a given block
2. Provide a basis for determining and defining a path ahead based upon well understood tradeoffs of performance vice capability evolution, schedule, and costs

Because of “grass roots” M&S development at the component, subsystems, and even element level and the adoption of a “capabilities-based” architecture perspective, there has been reluctance to use M&S to “define” systems-level (including C2/BM/C) evolution paths.

Findings – Scope and Integration (cont.)

- Need to also focus a significant M&S effort on exploring tradeoffs for formulation of future (Block 6 and beyond) architectures
  - There does not appear to be a coherent vision for what M&S capabilities are needed so that future system evolution paths can be assessed
  - Increased attention is needed for M&S to also support developing and implementing a long term vision for global missile defense
  - BMDS cannot be flight tested as a system against any significant portion of the "operating envelope"
  - M&S validated by IV&V and systems integration "tests" will represent THE SYSTEM to the user
  - The users - STRATCOM and the RCCs - do not have the resident capability to develop models of BMDS system performance
    - They are charged with planning and execution with assurance to the NCA of how the system and its elements will perform
    - BMDS M&S needs to include support for this warfighting function

Modeling and simulation should be elevated in status within MDA so that it is viewed as the deliverable representation of "the system" both to MDA and, importantly, to the user.

A credible M&S representation of BMDS, as verified in limited test bed demonstrations, will provide the user and National Command Authority emulation of system-level performance over all corners of the envelope against adversary threats yet to be developed.

M&S thus needs to be the basis for the formulation of Block 6 and subsequent architectures. Importantly, if used with rigor across both systems and C2/BM/C, M&S can assure that evolution paths are not precluded for future BMDS development.

Findings – Scope and Integration (cont.)

- Integrated system effectiveness – achieving the intended end capability – is likely to also depend significantly upon offense/defense integration
  - The need for USSTRATCOM and/or RCCs to defend areas of responsibility (AORs) effectively against potential threats require preemptive strikes against some launch areas
    - While not an assigned MDA mission, the M&S program needs to account for it
    - MDA-developed systems will be the primary source of precision data for attack
  - STRATCOM, to improve the RCC capability to defend their AORs, must offer a global missile defense perspective for the benefit of all and provide the command and control services necessary to support global missile defense
  - M&S of the BMDS operation will be the basis for STRATCOM and the RCCs to:
    - Develop contingency plans for the AORs and global missile defense
    - Characterize the integration of offensive and defensive forces
    - Assess the likely effectiveness of the deployed system against evolving threats
  - The BMDS M&S "deliverable" must be credibly integrated into force planning and execution tools

Change 2 to the Unified Command Plan assigns global missile defense responsibilities to USSTRATCOM. To fill this role, USSTRATCOM and the regional combatant commands will need a verified capability to model and simulate the system's behavior.

Measures of effectiveness of missile defense will include area protected (in the United States, or regions of the world with U.S. deployed forces, friends, and allies) and launch area denial. The latter, a measure of the threat posed from regions of the globe, may well only be countered through precision strike of launchers in the area. MDA-developed systems will be the primary source of precision data for attack.

This consideration alone is rationale for strong coupling of offense and defense. In addition, USSTRATCOM—with global strike, missile defense, and global intelligence, surveillance, and reconnaissance (ISR) integration responsibilities—has the need to be able to use elements of the system efficiently and effectively. Modeling and simulation of the BMDS should account for these integration objectives.

Effective modeling and simulation of the global BMDS concept of operations will provide USSTRATCOM and the regional combatant commanders with the capability to develop architecture evolution plans, understand the performance of the system in spiral development, and plan (and train) for scenarios of the future.

Findings – Scope and Integration (cont.)

- Effective M&S support of block evolution/system integration phasing within spiral development approach demands effective M&S configuration control
  - In an environment of day-to-day changes, "phased" system integration as a result of test bed evaluations, spiral development, and block changes to architecture (capability) options
- Air defense is not part of the current MDA M&S evaluation task
  - Several of the elements (e.g., PAC-3, Aegis) have air defense responsibilities and obvious self defense priorities
  - The systems level BMDS M&S must include representation of the resource allocation and C2/BM/C issues resident in multi-mission elements to address systems-level performance

The entrepreneurship of code developers, the evolution of components, subsystems, and elements of the system through spiral development, and the lack of systems engineering driven requirements modus operandi, makes "configuration control" of modeling and simulation produce a formidable set of challenges.

Modeling and simulation for elements of the system and for future BMDS evolution do not reflect the capabilities inherent or essential for operation in many of the elements. For example, Aegis and Patriot self-defense objectives against cruise missiles are not accounted for in BMDS models. Thus, the resource allocation models viewed to be available for ballistic missile defense applications are in question.

Findings

- Modeling & simulation evolution towards a systems level product suitable for assessing capabilities and making systems trade-offs for future spirals appears diffused, complicated, and slowed by the split between systems level and C2/BM/C M&S developments
- BMDS M&S activities need to fully account for net-centric and GIG-BE evolution
  - These activities need to provide for rapid, collaborative planning, command and control support for the engagement environments facing STRATCOM and the RCCs
  - Fusion of ISR and weapon system sensor data for BMDS implementation needs to be explicitly included in system level M&S

The current division of M&S efforts between systems and C2/BM/C seems detrimental to developing an effective integrated, global BMDS (one that uses multi sensor discrimination). Communications initiatives (NCES and GIG-BE) have been largely ignored. Thus, data fusion and global interoperability are not modeled (or defined).

BMDS "global system level" models must account for integrated elements and C2/BM/C representing a system-of-systems in order to capture how the system "works" and how it can be used against potential threat scenarios.

Findings (cont.)

- Configuration control will be critical in developing and using the models and simulations for future spirals
  - Definition (or identification) of a standard architecture is required for each block so that the M&S software is compatible
  - The "handover" (model update) for subsequent blocks must be managed through configuration control
- IV&V and accreditation is currently performed on certain (not all) BMDS M&S models internally
- Two relevant models are the DOE Weapons Lab "peer review" process and the NQA software development standard – the current MDA approach does not appear to meet this standard
- Internal BMDS M&S IV&V and accreditation does not appear to have the organizational stature nor resources for the task(s) at hand

Modeling and simulation does not appear to have the "status" within MDA to achieve the needed capability. Budget, independence, and direct reporting responsibilities to MDA leadership are essential.

MDA needs to determine a standard technical architecture for the interface of the M&S block components. This decision should be made within 6 months in order to give industry clear direction. The high level architecture (HLA) is currently designated by DoD, but recent commercial-of-the-shelf options such as the subscriber/ publish software should be considered as an alternative. A small team composed of people with relevant software experience from government, contractors, and FFRDC's should be tasked to make recommendations to MDA. After making a recommendation, MDA should then require all contractors to adhere to the standard, starting with Block 2008 capabilities.

Recommendations

- View systems level M&S to be a deliverable to USSTRATCOM
  - On behalf of STRATCOM and the RCCs, STRATCOM should offer flag level assignment to (at) MDA responsible for "buying" (accepting) the systems level BMDS M&S capability for the user
- STRATCOM should use the combined expertise resident at the JNIC and STRATCOM to develop an integrated offense/defense M&S capability based upon the MDA deliverable
- MDA should assign a senior individual responsibility for BMDS M&S for each block
  - That individual must have the authority, budget, and staff to integrate systems and C2/BM/C M&S efforts into a credible "BMDS M&S deliverable" for each block to include responsibility for configuration control and utility of the product for the user
- MDA should assign a senior individual to lead IV&V and accreditation
  - To report independently and directly to Director, MDA
  - With the authority and budget to execute the desired independent program

Recommendations on this and the next two charts are self explanatory.

Recommendations (cont.)

- Top level BMDS M&S tools should be used to establish tradeoffs for future architectures based upon well understood (common fidelity) systems and C2/BM/C representations
- BMDS M&S should account for the other operational responsibilities resident in the elements (e.g., air defense, cruise missile defense) so that the operational effectiveness of the system as a whole can be reliably assessed
- MDA should assess utilization of the NQA approach to force configuration control, regimen, and appropriate peer review of the systems level BMDS M&S capability

Recommendations (cont.)

- MDA should immediately assign a small team of government staff supported by contractors to consider various architecture standards (e.g., HLA) with the objective of recommending a BMDS M&S standard within six months. MDA should promulgate the standard and require all contractors to adhere, starting with Block 2008
- MDA should integrate the systems and C2/BM/C M&S approaches so that a useable M&S characterization of BMDS can be efficiently and effectively produced

APPENDIX A. TERMS OF REFERENCE

THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

ACQUISITION,
TECHNOLOGY
AND LOGISTICS

3 0 JAN 2003

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference--Defense Science Board Task Force on Ballistic Missile Defense – Phase III (Modeling and Simulation)

In coordination with guidance from the Director, Missile Defense Agency, you are requested to form a Defense Science Board (DSB) Task Force on Ballistic Missile Defense -- Phase III (Modeling and Simulation).

Modeling and simulation (M&S) plays a key role in both developing the Ballistic Missile Defense System and assessing its likely effectiveness. In this context, modeling and simulation covers the gamut from detailed engineering simulation of components to systems of systems simulations.

Specific purposes of this phase of the task force are to assess:

) the scope of the modeling and simulation effort

2) the appropriateness of the level of fidelity of classes of simulations

3) The impact of communications in the end-to-end models

4` the approaches to ensuring the validity of simulations for all uses, including exercises and wargaming done for training and operations concept development

5) additional opportunities for M&S contribution to BMDS development and evaluation

The Task Force is asked to address these issues in a system of systems context with particular emphasis on battle management systems, command and control systems, and the global sensor system. The Task Force is also asked to provide advice on the state of modeling and simulation for use in assessing overall performance of segments of the BMDS, e.g., ground-based midcourse intercept system, space-based interceptor system.

This Task Force will be co-sponsored by me as the Under Secretary of Defense (Acquisition, Technology, and Logistics) and the Director, Missile Defense Agency. Dr. William R. Graham and General Larry D. Welch, USAF (Ret) will serve as Task Force Co-Chairmen. Mr. Paul Hoff will serve as the Executive Secretary; and LtCol Roger W. Basl, USAF, will serve as the DSB Representative.

The Task Force will be operated in accordance with the provisions of P.L. 92-463, the "Federal Advisory Committee Act," and DoD Directive 5104.5, "DOD Federal Advisory Committee Management Program." It is not anticipated that this Task Force will need to go into any "particular matters" within the meaning of Section 208 of Title 18, United States Code, nor will it cause any member to be placed in the position of acting as procurement official.

E.C. Aldridge, Jr.

APPENDIX B. TASK FORCE MEMBERSHIP

Chairmen

Dr. William Graham	National Security Research
Gen Larry Welch, USAF (Ret)	Institute for Defense Analyses

Members

LtGen Bruce Brown, USAF (Ret)	Institute for Defense Analyses
Mr. Douglas Bryant	Teledyne Brown Engineering
Dr. Greg Canavan	Los Alamos National Laboratory
Dr. Sean Collins	SPARTA, Inc.
Dr. Julian Davidson	Davidson Technologies, Inc.
Mr. John Elwell	The Charles Stark Draper Laboratories
Dr. Delores Etter	U.S. Naval Academy
Dr. Eric Evans	MIT Lincoln Laboratories
Dr. John Foster	Northrop Grumman Space Technology
Dr. Jack Hammond	Lockheed Martin
RADM Wayne Meyer, USN (Ret)	W.E. Meyer Corporation
Dr. Robert Strickler	Private Consultant

Executive Secretary

Mr. Paul Hoff	Missile Defense Agency

Defense Science Board Representative

LtCol Roger Basl, USAF

Government Advisors

MAJ Tom Cook, USA	Missile Defense Agency
COL Kevin Greaney, USA	Missile Defense Agency
Mr. Keith Englander	Missile Defense Agency

Staff

Mr. Frank Brown	MDA SETA Support
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APPENDIX C. GLOSSARY OF ACRONYMS AND ABBREVIATIONS

ABL	Airborne Lasers
AOR	Area of Responsibility
BMC	Battle Management and Communications
BMDS	Ballistic Missile Defense System
BOC	Basis of Confidence
BPI	Boost Phase Intercept
C2	Command and control
C2/BM/C	Command and Control/Battle Management/Communications
CAPS	Commanders Analysis Planning and Simulation
CEC	Cooperative Engagement Capability
CMM	Capability Maturity Model
CONOPS	Concepts of Operations
DIS	Distributed Interactive Simulation
DoD	Department of Defense
DOE	Department of Energy
DSB	Defense Science Board
EADSIM	Extended Air Defense Simulation
EADTB	Extended Air Defense Test Bed
EDO	Emergency Defensive Operations
EKV	Exoatmospheric Kill Vehicle
EO	Electro-Optic
FFRDCs	Federally Funded Research and Development Centers
GBI	Ground-Based Intercept
GBR	Ground Based Radar
GMD	Ground-Based Midcourse Defense
HLA	High Level Architecture
HTK	Hit-to-Kill
HWIL	Hardware-in-the-Loop

ICBM	Intercontinental Ballistic Missile
IDO	Initial Defensive Operations
IMD	Integrated Missile Defense
IMU	Inertial Measurement Unit
IRBM	Intermediate Range Ballistic Missile
IRT	Independent Review Team
ISR	Intelligence, Surveillance, and Reconnaissance
IV&V	Independent Verification and Validation
IVV&A	Independent Verification, Validation, and Accreditation
JNIC	Joint National Integration Center
JPL	Jet Propulsion Laboratory
JWARS	Joint Warfighting System
JTWARS	Joint Theater Warfighting System
KI	Kinetic Interceptors
KV	Kill Vehicle
M&S	Modeling and Simulation
MDA	Missile Defense Agency
MDAP	Major Defense Acquisition Program
MDSE	Missile Defense System Exerciser
MDWAR	Missile Defense Warfare Assessment and Research Simulation
MRBM	Medium Range Ballistic Missile
MSX	Midcourse Space Experiment
NQA	Nuclear Quality Assurance
PAC 2/3	PATRIOT Advanced Capability, level2/level 3
PEELS	Parametric Endo-Exo Lethality Simulation
PES	Probability of Engagement Success
RCC	Regional Combatant Commands
RF	Radio Frequency
SBIRS	Space Based Infrared System
SM-3	Standard Missile-3
SPO	System Program Office
SPY-1	AEGIS Radar
SRBM	Short Range Ballistic Missile
SSGM	Strategic Scene Generation Model

STSS	Space Tracking and Surveillance System
T&E	Test & Evaluation
THAAD	Theater High Altitude Area Defense System
UEWR	Upgrade Early Warning Radar
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology and Logistics
USSTRATCOM	United States Strategic Command
VV&A	Verification, Validation, and Accreditation
XBR	X-Band Radar